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Natural mortality rate estimation and fishery characterization for white ulua (*Caranx ignobilis*) in the Hawaiian Islands

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ABSTRACT

Natural mortality rate for white ulua (*Caranx ignobilis*) was estimated to be approximately 0.89 $year^{-1}$ using the Inverse Method for Mortality and Growth Estimation (IMMAGE) approach on catch data from the Northwestern Hawaiian Islands. The fishery in the main Hawaiian Islands was characterized with IMMAGE as a dual fishery, with a net fishery targeting fish in the narrow size range of 27-40 cm SL, and a hook and line fishery targeting fish from approximately 70 cm SL upward. The size-selective characteristics of the net fishery appear to be related to a combination of size-dependent stock vulnerability and gear selectivity. Proper designation of the selection curve for each fishery is shown to be critical for accurate assessment of the stock. Commonly used biological indicators based on catch statistics are shown to be of limited value when there are highly size-selective fisheries. The white ulua population in the main Hawaiian Islands does not appear to be stressed from fishing as the biological indicators would suggest. This analysis modifies the IMMAGE approach for application to multiple fishery stocks.

INTRODUCTION

White ulua (*Caranx ignobilis*) is a common, shallow water carangid in Hawaiian waters, and is a bottomfish management unit species (BMUS) monitored within the fishery management plan (FMP) of the Western Pacific Regional Fishery Management Council (WPRFMC). Fishery monitoring indicators include mean weight in the catch and percent immature fish in the catch. The value of these indicators relies on the assumption that, beyond a certain size, the size structure of the catch represents the size structure of the current population (termed logistic gear selectivity). When this assumption is true, a low mean weight in the catch relative to weight at maturity or a high proportion of immature fish in the catch may be an indication of possible overfishing. The occurrence of many immature fish in the main Hawaiian Island (MHI) white ulua catch (Figure 1) could be cause for concern if this pattern accurately resembles the underlying population size structure. Based on this type of catch data, Ralston and Kawamoto (1988) suggested that white ulua may be recruitment overfished in the MHI. Because of this and other concerns, such as recent low estimates of Spawning Potential Ratio (SPR, Somerton and Kobayashi 1990b), the Scientific and Statistical Committee (SSC) of the WPRFMC has recently requested regulatory computer simulations for white ulua similar to those done for deepwater snappers to investigate effects of changes in size limits or fishing closures (Kobayashi 1993, Somerton and Kobayashi 1990a, 1990c). Preliminary attempts to simulate the white ulua fishery were successful in duplicating the NWHI catch length frequency distributions, but were unsuccessful in duplicating the observed MHI catch length frequency distributions. This prevented further study with regulatory simulations for the MHI fishery. Apparently, the white ulua fishery in the MHI is more complex than in the NWHI (and fisheries for most other species), and cannot be modeled as a simple, single fishery with logistic gear selectivity. The purpose of this study was to investigate white ulua more thoroughly and characterize the fishery with an appropriate pattern of gear selectivity. This would allow regulatory simulations to be run in the event that the fishery indicators are truly indicative of overfishing in the MHI.

MATERIALS AND METHODS

Natural mortality rate and fishery parameters for white ulua were estimated using an age-structured, length-expressed, equilibrium population model coupled with a nonlinear parameter search algorithm. This particular approach is called the Inverse Method for Mortality and Growth Estimation (IMMAGE) and was originally developed for use with larval Hawaiian anchovies (Somerton and Kobayashi 1992). The method was found to be generally applicable for any analysis that deals with catch size distributions that are biased by size-dependent gear selectivity. The original version required an independent estimate of the gear selection curve, but more recent modifications (Kobayashi in prep.) enable IMMAGE to internally estimate the gear selection curve. This version of IMMAGE requires growth parameters, length-weight conversion parameters, and size at maturity. Growth of white ulua was assumed to follow a vonBertalanffy growth model, where L_t is mm SL at age t years and is defined as:

$$L_t = L_\infty (1 - e^{-K(t-t_0)}), \tag{1}$$

where L_∞ = 1838 mm SL, K = 0.111 $years^{-1}$, and t_0 = 0.097 years (Sudekum et al. 1991). Weight (W in grams wet weight) was assumed to be related to length (L in mm SL) by the following relationship:

$$W = aL^b, \tag{2}$$

where a = 2.30×10^{-5}, and b = 2.977 (Sudekum et al. 1991). Size at maturity is approximately 600 mm SL, which corresponds to an age of 3.5 yr and a weight of 9.5 lb (Sudekum et al. 1991).

Natural mortality was estimated by applying IMMAGE to length frequency distributions from areas assumed to be relatively unfished. In these areas, natural mortality (M) is approximately equal to total mortality (Z) since fishing mortality (F) is negligible and Z = M+F. White ulua is a relatively minor component of the bottomfish catch in the NWHI (e.g., Kawamoto 1992) and is not generally targeted by fishermen. This is due to the higher market demand of the more sought after snappers and groupers and concerns of ciguatoxic fish (e.g., Kimura et al. 1984, Ito et al. 1984). Catches from these areas were assumed to be suitable for estimating natural mortality rate, and two independent sources of NWHI white ulua size data were analyzed (Figure 1). The first data set is a 1984-91 aggregate length frequency distribution of white ulua caught in the NWHI and sold at the Honolulu auction. These data were collected primarily by National Marine Fisheries Service (NMFS) personnel, although in some years Hawaii Division of Aquatic Resources (HDAR) and WPRFMC personnel also participated. This data set comprised 7,654 fish. The second data set is a 1981-82 aggregate length frequency distribution of white ulua caught in the NWHI from HDAR: chartered fishing vessels as part of a larger investigation of bottomfishing activity in the NWHI. This data set comprised 1,099 fish. Normally, IMMAGE would require a user input value of M, and would then estimate F and the gear selection curve. For M estimation, the internal M was set to 0, and the resulting F estimate was assumed to be an estimate of M and Z. This version of IMMAGE was applied separately to the Honolulu auction data and the HDAR charter data. Multiple years of data were aggregated in an attempt to approximate equilibrium conditions. It should be noted that white ulua identification, even juvenile identification, is not problematic, and the white ulua fishery data is unlikely to be contaminated by other species of papios (smaller carangids) or uluas (Kurt Kawamoto, pers. comm.).

After M is estimated, this value could be preset in the IMMAGE program, allowing application to more heavily fished populations such as the MHI (Honolulu auction catch data set, n = 17272, 1984-91). IMMAGE could then estimate F and the gear selection curve. While the fishery parameters can freely take on any value, the model is constrained by the type of fishery that is assumed to exist; i.e., the *shape* of the curve designated for the gear selection curve. For example, applications involving some towed nets and hooks can assume a logistic type of selection curve, where there is a gradually increasing gear "effectiveness" with fish size until a point where complete effectiveness is reached and maintained at all larger sizes; i.e., all fish exposed to the gear are caught. This is simply a more realistic version of the often used "knife-edge" selectivity pattern, where complete gear effectiveness is assumed to be attained at a single size. These types of gear selectivity patterns are convenient to deal with because, beyond a certain size, the catch size structure approximates the population size structure. Determination of this size can be relatively straightforward. On the other hand, a gillnet, for example, is size selective at both smaller sizes and larger sizes because only fishes within certain threshold body dimensions will be retained in the meshes. Obviously, the catch from this type of gear will yield very little useful information about the size structure of the underlying population. The preliminary application of IMMAGE to MHI ulua assumed a single logistic gear selection curve (representing a single hook and line fishery) similar to that used for the deepwater snapper analysis:

$$Q_1=\frac{1}{1+e^{-a_1(L-b_1)}}, \tag{3}$$

where Q_1 is the index of gear effectiveness ranging from 0-1, L is fish length, and a_1 and b_1 are parameters to be estimated. Since this was unsuccessful in representing the MHI fishery, alternative types of fishery configurations were explored in the model. These included adding a second fishery represented as either:

another logistic curve:

$$Q_2=\frac{1}{1+e^{-a_2(L-b_2)}}, \tag{4}$$

a symmetrical bell-shaped normal curve:

$$Q_2=e^{-\frac{1}{2}\left(\frac{L-b_2}{a_2}\right)^2}, \tag{5}$$

an asymmetrical lognormal curve:

$$Q_2=\frac{e^{b_2-\frac{a_2^2}{2}-\frac{(\mathrm{Log}(L)-b_2)^2}{2a_2^2}}}{L}, \tag{6}$$

an asymmetrical gamma curve:

$$Q_2=\left(\frac{L}{(b_2-1)\,a_2}\right)^{(b_2-1)} e^{b_2-1-\frac{L}{a_2}}, \quad or \tag{7}$$

an asymmetrical dual logistic curve:

$$Q_2=\left(\frac{1}{1+e^{-a_2(L-b_2)}}\right)\left(\frac{1}{1+e^{a_3(L-b_3)}}\right), \tag{8}$$

where a_2, b_2, a_3, and b_3 are parameters to be estimated. Gear selection curve Equations (6) and (7) are from Millar (1992). Adding the additional fishery to IMMAGE increased the number of parameters from 4 to 7 for Equations (4)-(7), and 4 to 9 for Equation (8). Each second fishery was assumed to operate with an independent F_2 from the initial logistic fishery (F_1). A scaling parameter, N_0, also a measure of recruitment, was required for each application. For all model configurations, IMMAGE was run until the best fitting parameters were obtained.

RESULTS AND DISCUSSION

Natural mortality rate was estimated to be 0.98 year^{-1} from the Honolulu auction data set, and 0.80 year^{-1} from the HDAR charters data set. The more recent Honolulu auction data might be expected to yield a slightly higher Z, if there is some component of F in the Z estimate. However, given the extremely fast growth rate of white ulua, I considered the two estimates equally and used an average value of M = 0.89 year^{-1} for further applications of IMMAGE.

IMMAGE results with different fishery configurations are summarized in Table 1, and the IMMAGE generated fits to the MHI length frequency data are shown in Figure 2. The actual gear selection curves multiplied by their corresponding F estimate are shown in Figure 3. The single logistic fishery configuration (henceforth referred to as "simple") yielded a relatively high R^2, primarily by capturing the peak in the 27-40 cm SL range with a nearly knife-edge selection curve. However, the fishing mortality required to describe the declining right side of the large peak cannot explain the observed catches of fish larger than approximately 60 cm SL. Allowing another logistic fishery (henceforth referred to as "double") aided the model, but still the fishing mortality of the first fishery does not leave enough large fish for the second fishery to catch, regardless of the magnitude of the second fishery. For clarity, the fishery operating on smaller fish will now be referred to as the first fishery, and the fishery operating on larger fish will be referred to as the second fishery. Both the simple and double fishery configurations exhibit clear lack of fit at sizes larger than 50-60 cm SL. The symmetrical normal curve fishery (henceforth referred to as "normal") allowed fishing magnitude of the first fishery to gradually diminish at both smaller and larger sizes. The model clearly compromises on the degree of taper since the left side of the 27-40 cm SL peak is very steep, while the right side is more gradual in the observed catch. As a result of this shape constraint, even the peak values are poorly described, and the R^2 of this model is the worst of all configurations. In spite of this, the normal configuration appears to add further realism, since the larger size classes are now beginning to appear in the simulated catch. The lognormal and gamma configurations added skew or asymmetry to the first fishery gear selection curve. Unfortunately, the increase in R^2 is relatively minor, and the curves are only barely perceptible, by the naked eye, to be skewed from the normal configuration. The reason for this is that with only two parameters defining the location and nature of the curve, both the lognormal and gamma models have an intrinsic and complex constraint on the degree to which they can "skew," given a particular length scaling system. Only the dual-logistic configuration is free of such shape constraints, but this comes at the expense of additional parameters in the model. Fortunately the model proved to not be overparameterized, with a clearly defined solution that is quickly converged upon in the nonlinear parameter search algorithm. The dual-logistic configuration allows the nearly knife-edge entry to the first fishery and a gradual diminishment as the second fishery increases. This configuration yields the highest R^2, and there is very little lack of fit to the observed catch.

While the second fishery can be characterized as a simple, logistic, "bigger is better," hook and line fishery (e.g., Ralston 1990), the first fishery is more complicated. There is some evidence that this pattern may be caused by alternative gear types and perhaps supplemented with fish behavioral tendencies. It is known that a substantial number of small white ulua sold at the Honolulu auction are captured while they are in large schools using surround-type nets (e.g., bag, fence, and purse seine nets, Kurt Kawamoto, pers. comm.), but this information is not recorded on the data base. As a result, the white ulua catch contains an unknown number of fish caught using fishing gear with unknown size-selective characteristics. Furthermore, the net fishery only targets the schooling phase and is only effective in some habitats (i.e., certain water depths and bottom topographies), and may thus only encounter a size-selective fraction of the population due to fish behavior (termed size-selective stock vulnerability). This pattern can arise if schooling behavior changes with size or if there is size-dependent habitat segregation. For example, the nearly knife-edge entry to the net fishery appears to be related to the observation that white ulua tends to form large schools only when a particular size/age is reached. At this phase of the life history, white ulua becomes very vulnerable to the net fishery because the large schools are conspicuous to spotters. This size at entry to the net fishery does not appear to be related to the physical characteristics of the net; i.e., retention, extrusion, or gilling of fish by the meshes, since most of the nets used are relatively fine mesh and could conceivably capture smaller fish. The diminishment of the net fishery at larger sizes may be related to the size-dependent stock vulnerability described above (i.e., larger fish tend not to form large schools or occur in different habitats), size-dependent gear selectivity (i.e., gear avoidance by the larger, faster fish before the net can be closed off), or both. In summary, there appears to be a separate fishery that targets only the smaller fish related to the combined effects of size-dependent stock vulnerability and gear selectivity. The IMMAGE model can account for both of these processes, but cannot distinguish between them; both patterns would be included in the modeled gear selection curve.

The preceding may at first appear to be simply an exercise in model fine-tuning. However, the importance of a properly specified fishery model can be seen in the extremely different equilibrium SPR values that each model predicts from the same MHI catch data. Both the simple and double logistic fishery configurations estimate very low (<20%) SPR values. These are approximately what one would expect using the current biological catch indicators such as mean weight or percent immature. The addition of a fishery that operates over a narrow size range, consistent with a net fishery, dramatically changes the SPR, and the best fitting model predicts an equilibrium SPR of 77%. The predicted population size structures of 1) the unfished, virgin condition, 2) the simple fishery configuration, and 3) the dual logistic double fishery configuration are shown in Figure 4. Assessment methods which do not account for the size-dependent gear selectivity or stock availability patterns of the net fishery would underestimate population size and SPR by a factor of approximately 5.

A critical assumption of this analysis is that the Honolulu auction processes a representative cross section of the total MHI catch. While this is thought to be a relatively minor, easily fulfilled assumption for most single fishery stocks, the added complication of the dual fishery for white ulua requires that the relative amounts of catch from each fishery are adequately represented at the Honolulu auction. For example, the net fishery is currently accounting for 25% of total white ulua catch biomass, based on the Honolulu auction data and the IMMAGE fishery characterization, and this percentage is assumed to apply to the entire MHI white ulua fishery. If the net fishery contributes to the overall fishery more than the predicted 25% (related to size-dependent or fishery-dependent marketing strategies), then SPR could be overestimated because the magnitude of the net fishery is underestimated. Alternatively, if the net fishery contributes less to the overall fishery than the predicted 25%, then SPR could be underestimated because the magnitude of the net fishery is overestimated. For assessment purposes, the former case is of more interest with regard to conservative management; i.e., could SPR be perilously low if the net fishery is operating at a higher magnitude than predicted? To address this potential bias, the dual-logistic fishery configuration was run with higher than predicted values of fishing mortality rate for the net fishery. The net fishery F_2 was incrementally increased up to 1000% over initial (Figure 5), at which point the net fishery catch accounted for over 80% of the total catch biomass. Even at this point, SPR values are safely >30% (Figure 6). The resilience of stock structure to the magnitude of the net fishery appears to be related to the extremely fast growth rate of white ulua. The sizes vulnerable to the net fishery (27-40 cm SL) are quickly grown through in less than a year (Figure 7). Thus it would appear that modest errors in the representativeness of the Honolulu auction catch data should not seriously impact the general results of this study.

At present, there appears to be no need for management concerns regarding white ulua in the MHI. Previous assessment attempts (e.g., Ralston and Kawamoto 1988, Somerton and Kobayashi 1990b) appear to have been in error caused by excessive reliance on faulty catch indicators. The multiple fishery IMMAGE model may prove to be useful in evaluating other stocks that are exploited by multiple gear types or that exhibit size/age-dependent vulnerability.

ACKNOWLEDGMENTS

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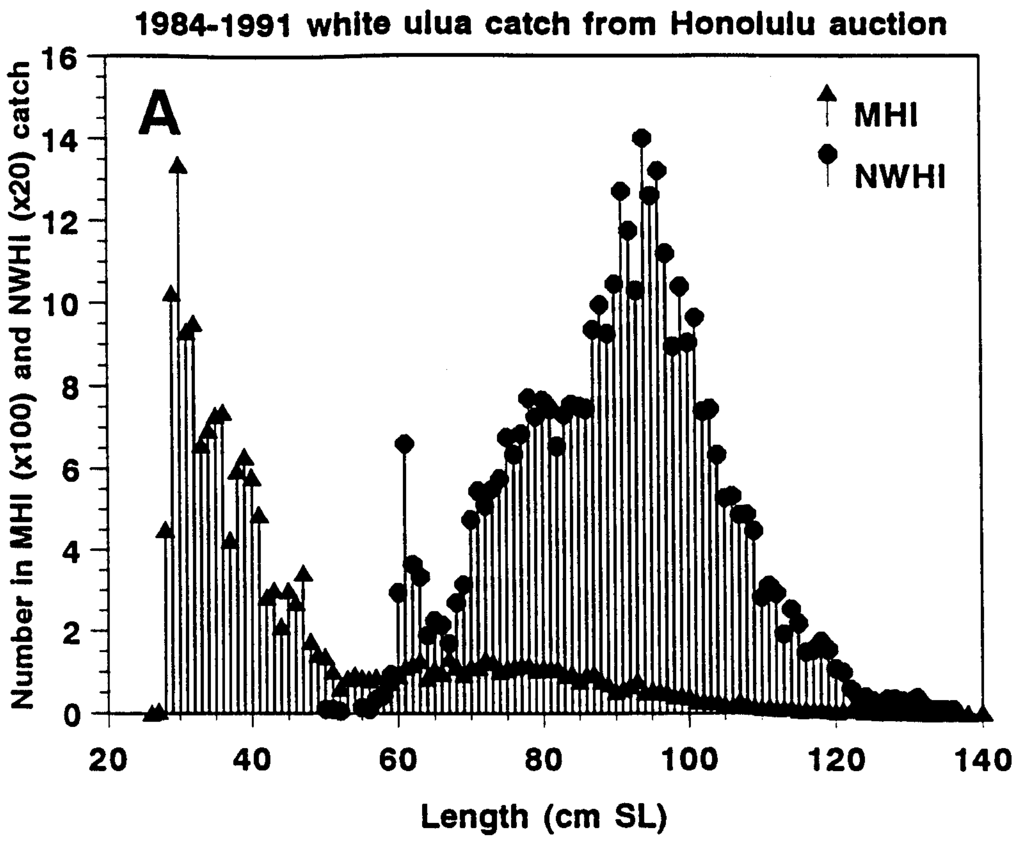
Table 1.--Summary of IMMAGE simulations for white ulua (*Caranx ignobilis*) with different fishery configurations. The data used are a 1984-91 aggregate length frequency distribution for the main Hawaiian Islands.

Type	N_0	Fishery 1	Fishery 2	R^2	SPR
Simple	1.99×10^5	$F_1 = 0.58$	-	88.88	13.62
		$a_1 = 4.49$	-		
		$b_1 = 27.31$	-		
Double	2.49×10^5	$F_1 = 1.03$	$F_2 = 0.42$	89.02	15.19
		$a_1 = 0.60$	$a_2 = 4.40$		
		$b_1 = 69.58$	$b_2 = 27.29$		
Normal	1.28×10^6	$F_1 = 0.52$	$F_2 = 0.07$	81.48	72.38
		$a_1 = 0.07$	$a_2 = 4.31$		
		$b_1 = 92.81$	$b_2 = 34.49$		
Lognormal	1.23×10^6	$F_1 = 0.74$	$F_2 = 0.08$	84.19	70.75
		$a_1 = 0.07$	$a_2 = 0.13$		
		$b_1 = 96.72$	$b_2 = 3.55$		
Gamma	1.18×10^6	$F_1 = 0.71$	$F_2 = 0.08$	83.29	69.69
		$a_1 = 0.08$	$a_2 = 0.62$		
		$b_1 = 94.95$	$b_2 = 56.90$		
Dual logistic	1.55×10^6	$F_1 = 0.23$	$F_2 = 0.07$	92.69	77.40
		$a_1 = 0.14$	$a_2 = 3.98$		
		$b_1 = 77.80$	$b_2 = 27.41$		
			$a_3 = 0.13$		
			$b_3 = 42.76$		



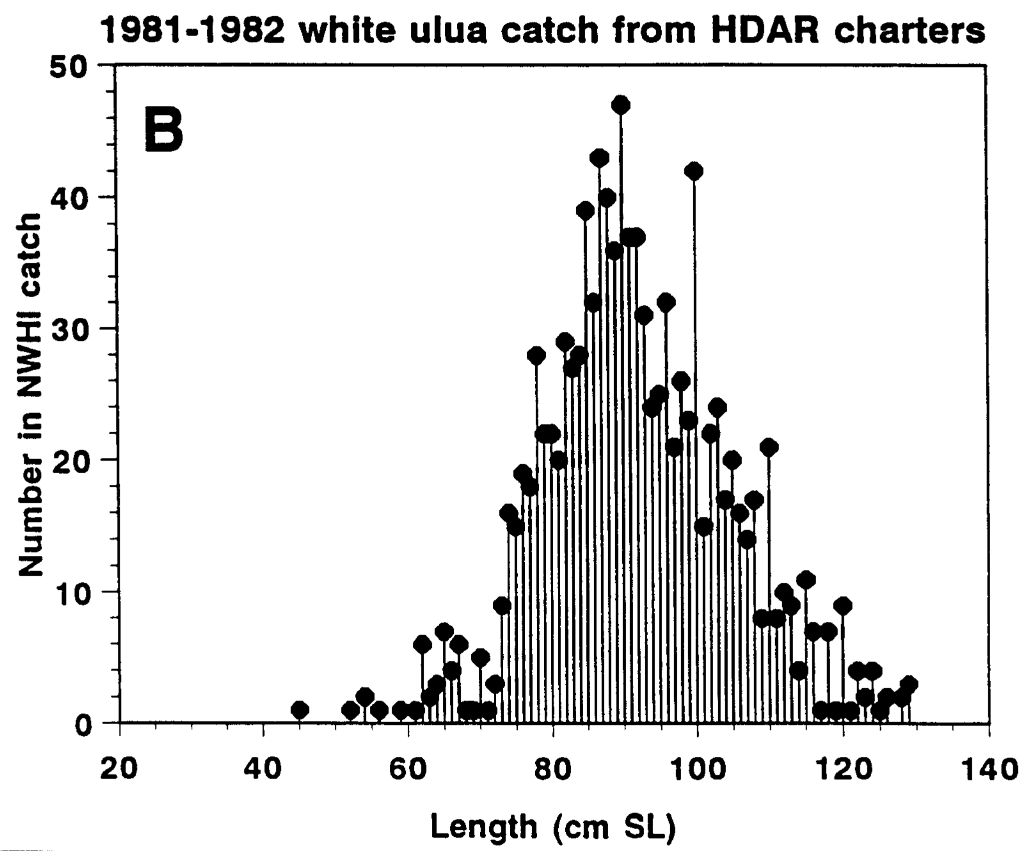


Figure 1.--Length frequency distributions of white ulua (*Caranx ignobilis*) catch within 1 cm SL bins from the Honolulu auction, 1984-91 (A) and from HDAR charters, 1980-81 (B).

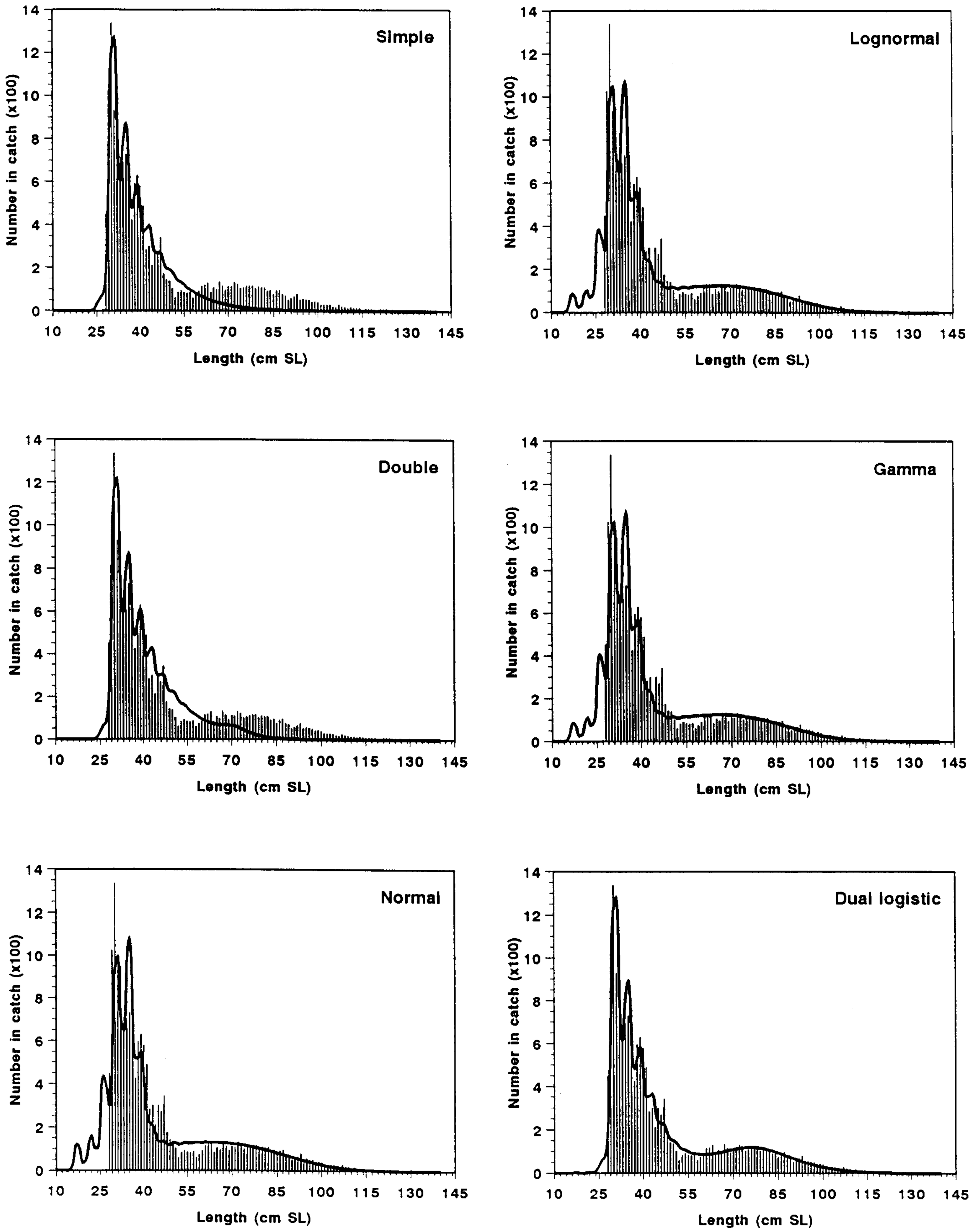


Figure 2.--Observed (vertical bars) and predicted (solid lines) values of white ulua (*Caranx ignobilis*) catch within 1 cm SL bins for Honolulu auction NWHI catch aggregated over the time period 1984-91.

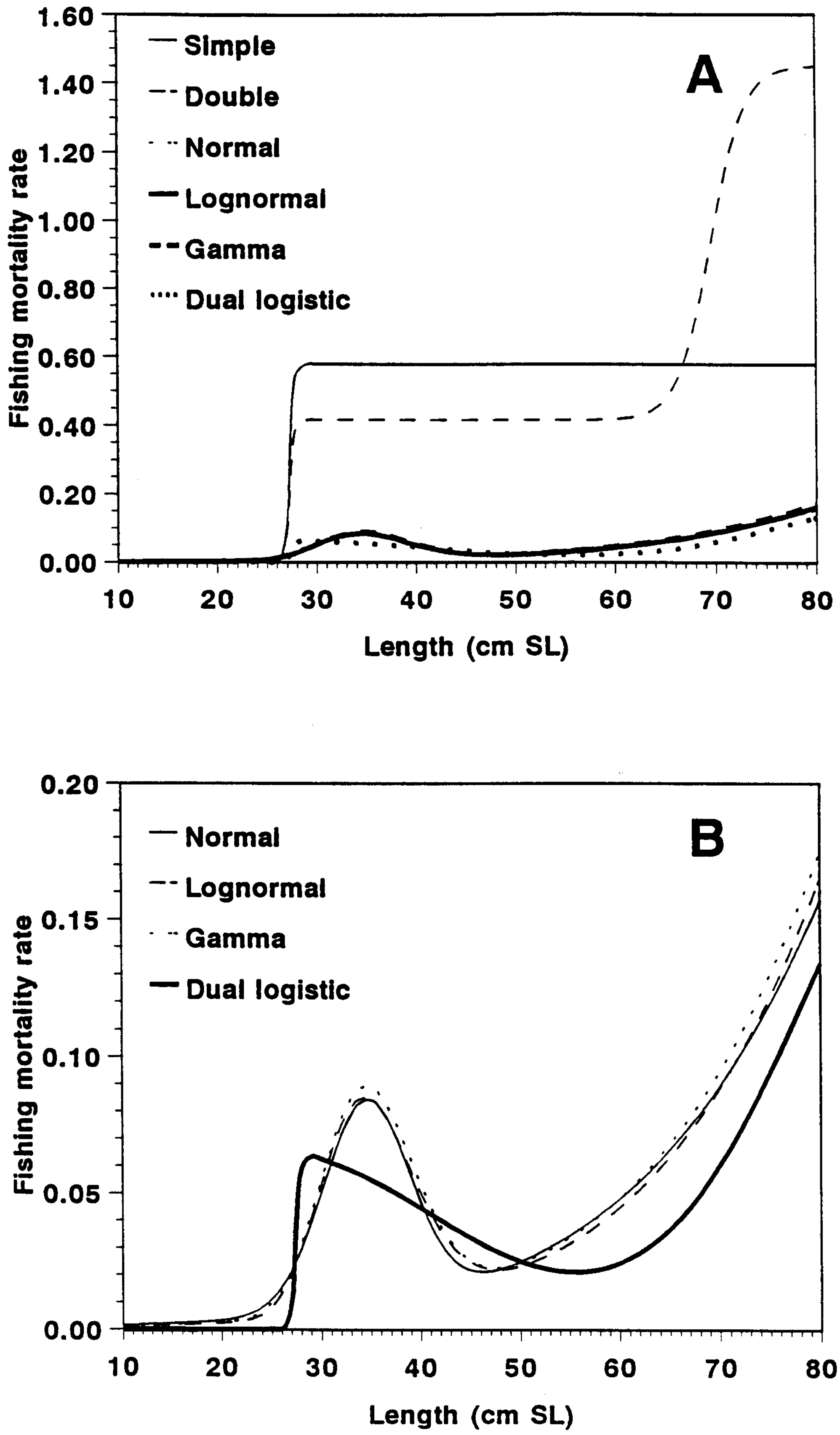


Figure 3.--Product of gear selection curves and estimates of fishing mortality rate plotted against fish size in cm SL. Upper panel (A) includes all six configurations attempted, and the lower panel (B) isolates the four size-selective fisheries. See text for explanation of fishery configuration types.

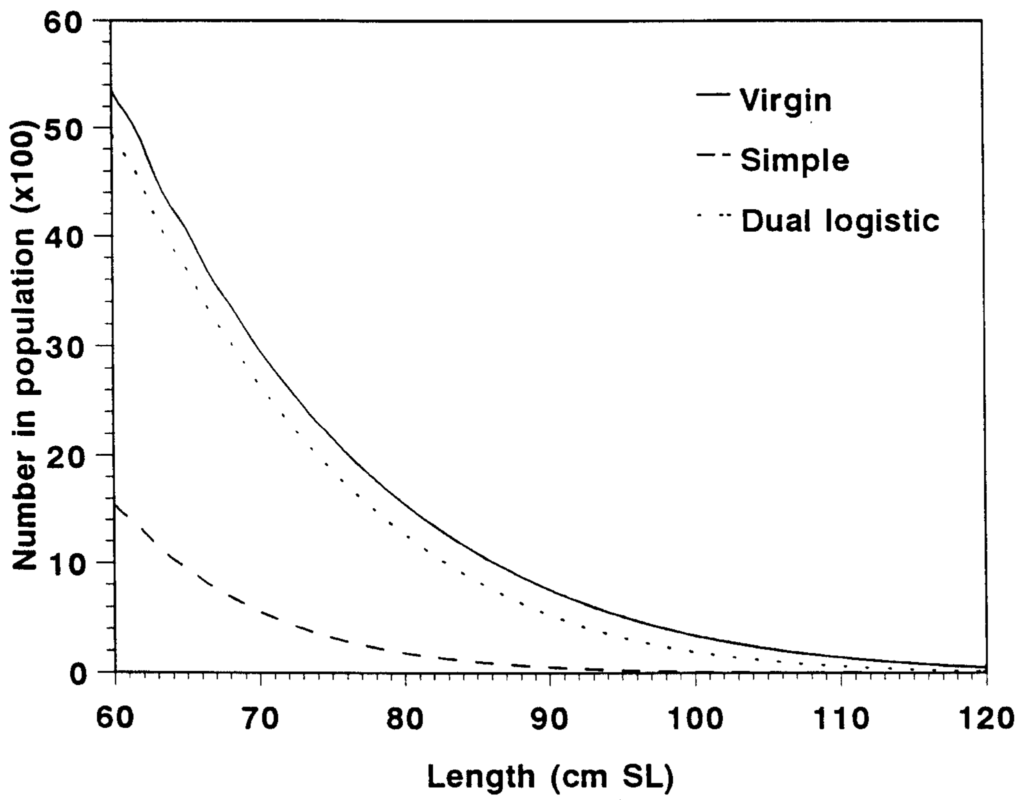


Figure 4.--Predicted population size structure of white ulua (*Caranx ignobilis*) for an unfished, virgin condition, the simple fishery configuration, and the dual logistic double fishery configuration. For comparative purposes, all three simulated populations were generated with the same scaling parameter ($N_0 = 1x10^6$).

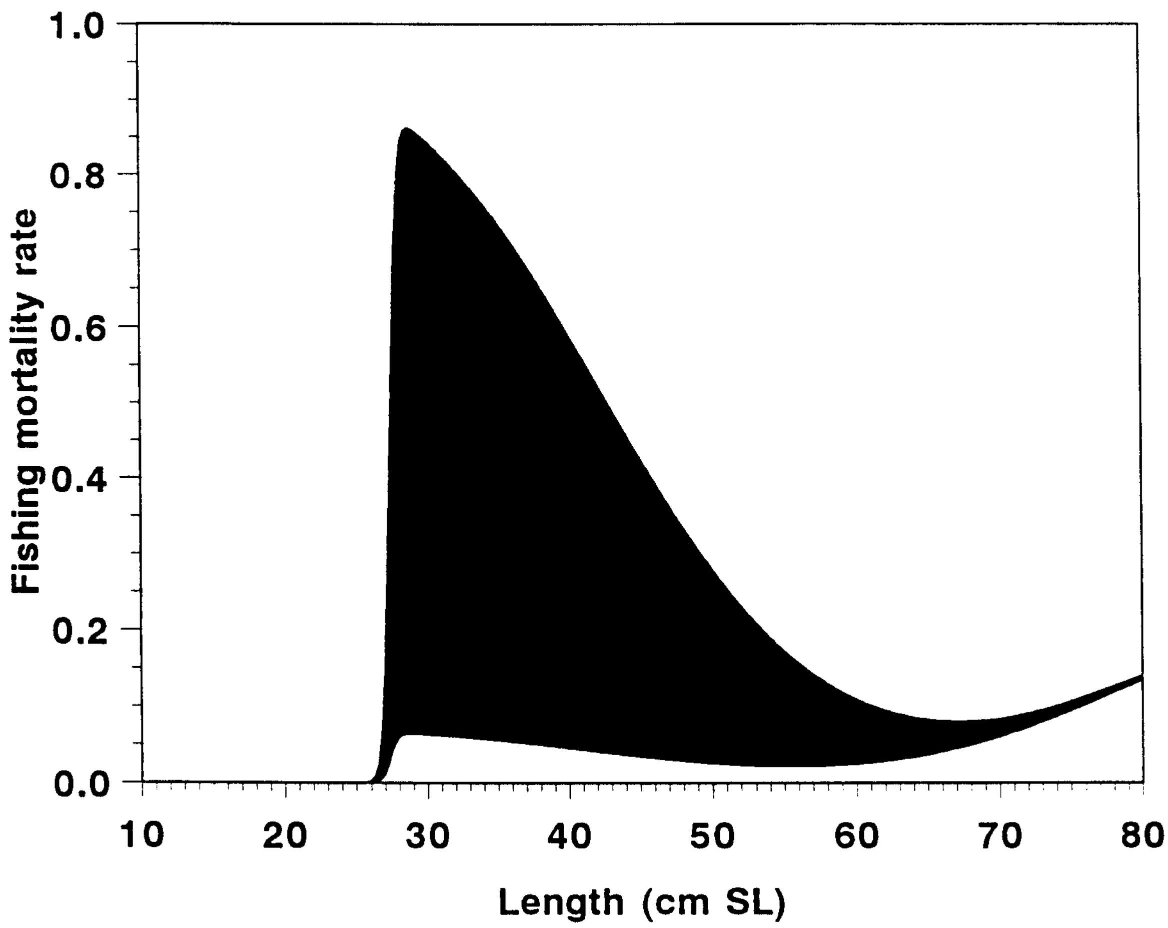


Figure 5.--Range of fishing mortalities applied in simulations to investigate sensitivity of white ulua (*Caranx ignobilis*) SPR to potential biases in Honolulu auction catch data. Lower limit of shaded region corresponds to the IMMAGE estimated solution. Upper limit of shaded region corresponds to a 1000% increase in the net fishery fishing mortality rate.

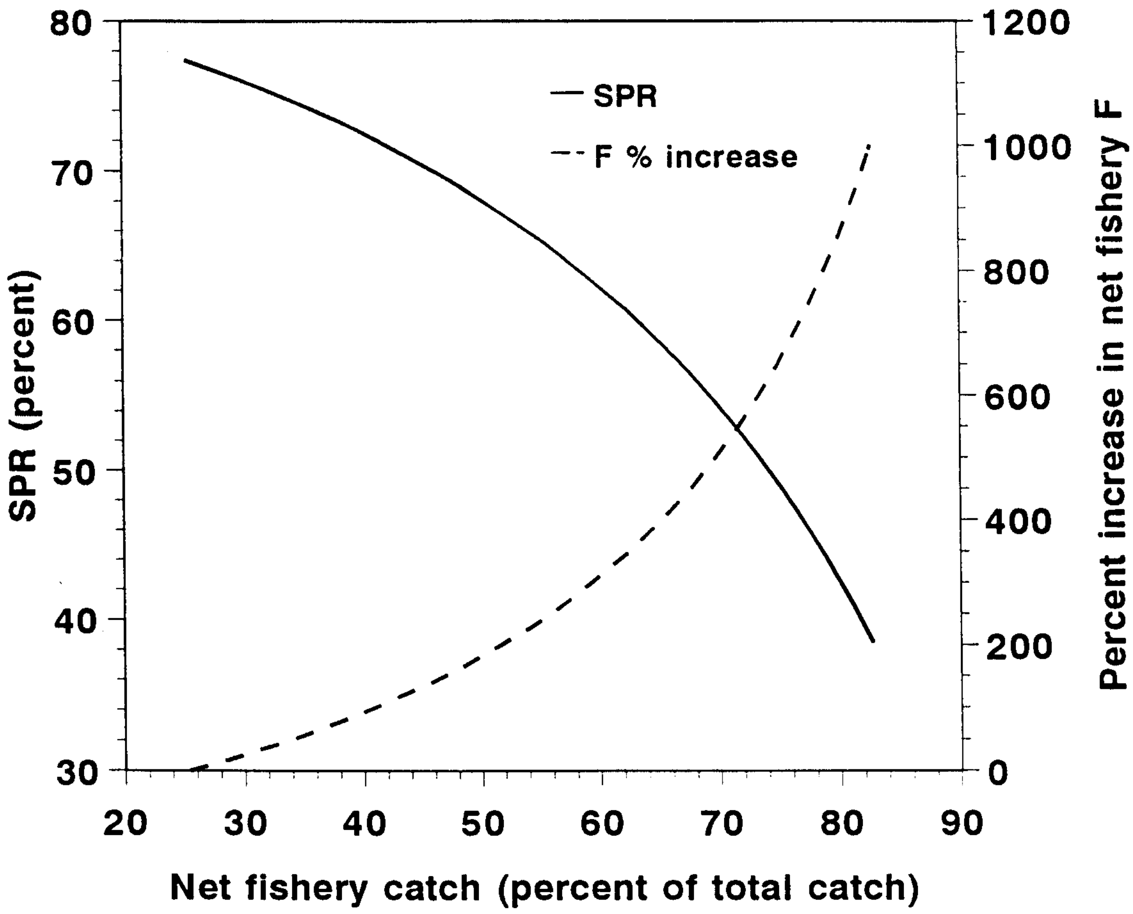


Figure 6.--IMMAGE estimates of the SPR for white ulua (*Caranx ignobilis*) and the F increases corresponding to different levels of the net fishery catch relative to total catch biomass.

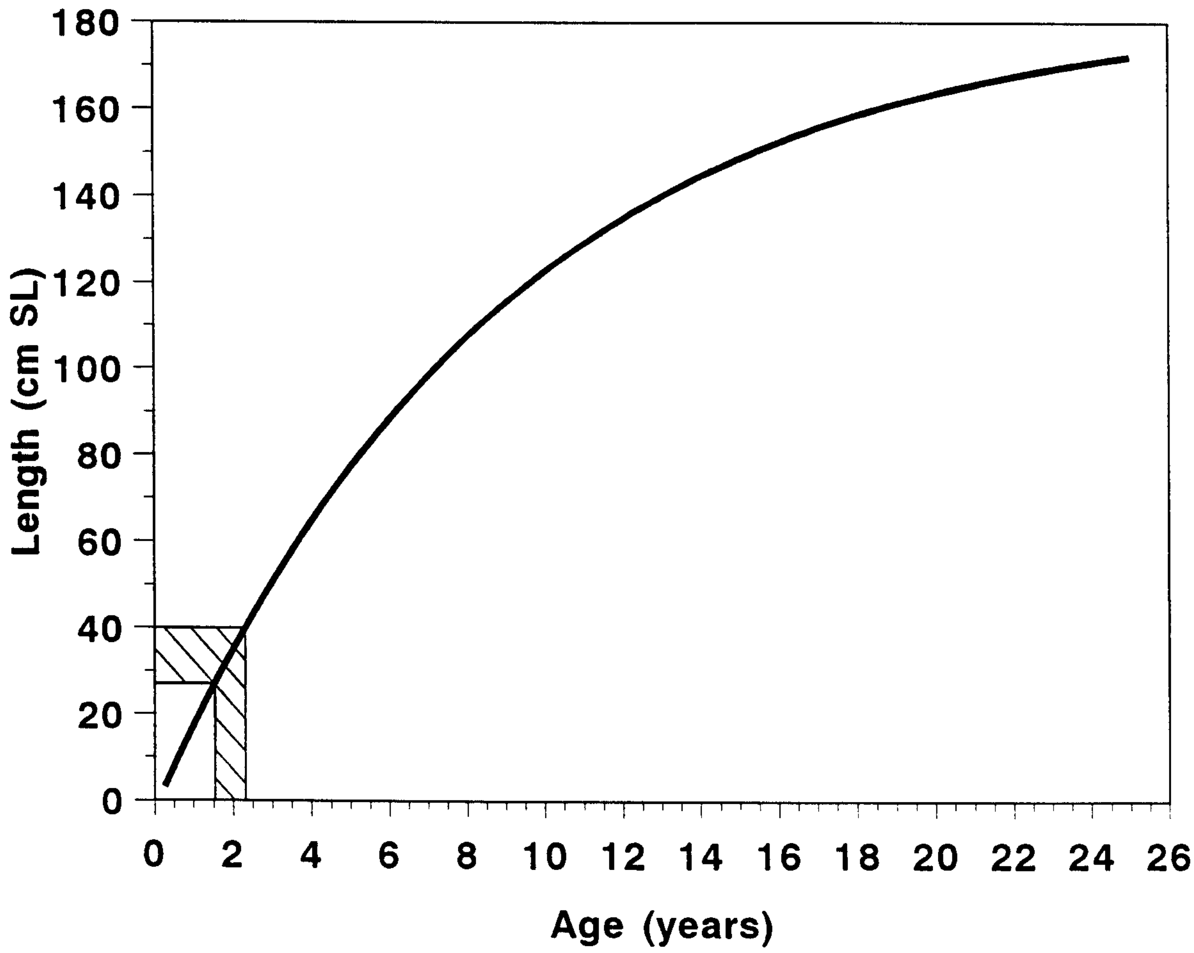


Figure 7.--Mean length at age for white ulua (*Caranx ignobilis*). Delineated area represents region of vulnerability to the MHI net fishery.